ENGINEERING FOR impact

mit 6.900

Lecture 4

February 16, 2023

MILO: requirements

We developed requirements based on internal staff discussions and talking with EDS staff

Why not with students?

1. It should accurately measure indoor air quality **
2. It should be portable ***
3. It should be possible to get the data off the device **
4. It should be a useful pedagogical exercise ***
5. It should maintain privacy *
6. It should be low cost *
7. It should be rugged and robust **
8. Multiple systems should be able to be used simultaneously ***
9. It should be easy to view the current and past data **
10. It should leverage MIT facilities **

MILO: from requirements to specifications

OK, let’s translate to specification document

What makes a good specification? No single approach for all of HW & SW

- It might be a well-defined metric and value (or range of values)
  - Example: BOM < = $100
  - Example: Measurement interval <= 10 min
- It could be qualitative
  - Example: HTTPS GET/POST for server comms
- It could directly imply a particular implementation
  - Example: Connectivity: WiFi 802.11a/b/g/n [2.4 GHz]
- Or you might not know what it should be yet
  - Example: Sensor accuracy: ???
- Or, you might not even know about that specification
  - Example: ???

A good spec is verifiable…else how do you know if you meet the specs and thus the requirements?

Don’t get hung up if you don’t know many of the specs at the beginning

The two most important points:

1. **Have a plan:** Work hard to plan ahead…and adjust the plan as needed

2. **Write stuff down:** Your team should have a single specifications document – a common understanding

MILO specifications [1/2]

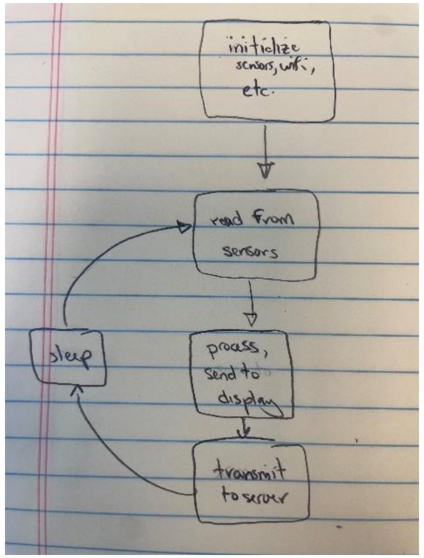
Ver. 1

- Financial
  - BOM <= $100 for electronics components, PCB
  - BOM: TBD for enclosure , mechanical parts
  - Time to market: ~8 weeks
- Regulatory
  - FCC certification for WiFi radio module
- Industrial design
  - Weight: < 300 g [~2 iphones]
  - Size: <10 x 10 x 10 cm [kinda small]
  - Survive 12” drop onto table
  - Enclosure materials: 3DP plastics available in EDS, laser-cut plastics available in EDS
- Environmental
  - Operating temperature: 0 to 70°C [commercial temp range]
  - Humidity: 10 to 95% RH
- Engineering
  - Sensors
    - Air quality: TBD
    - T: 0 to 70 °C
    - RH: 10 to 95% RH
    - Measurement interval: <=10 min
  - Compute
    - MCU: TBD
    - Firmware in C/C++
  - Comms
    - At least WiFi 802.11a/b/g 2.4 GHz
    - 5 GHz would be nice [801.22n]
    - WPA2-Enterprise w/ PEAP (MSCHAPv2) authentication and TLS encryption [this is what MIT Secure wants]
  - Energy management
    - LiPo battery
    - Lifetime between charging: >12 h
  - Server
    - Machine TBD, one for each student
    - SSH access for students, and staff
    - OS: Linux
    - Web server: NGINX
    - HTTPS GET/POST connections
    - DB: SQLite

MILO specifications [2/2]

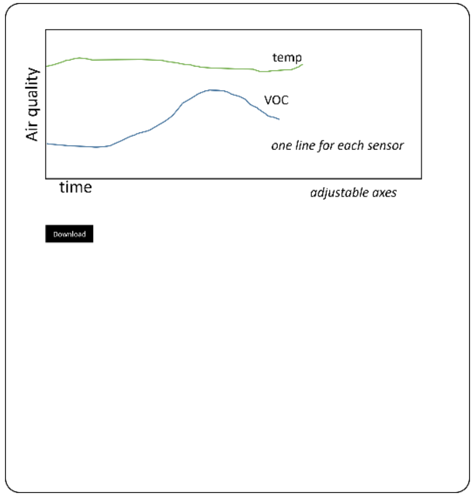
Ver. 1

- Firmware



- Still to specify
  - How to reset?
  - Data processing and what is transmitted
  - Sleep state, interval

- Software [on server]
  - Store data perpetually in SQLite table
    - Fields: Index number, Timestamp, RH, T, AQ measurements
    - No location information transmitted (or stored)
  - Web front-end
    - Framework: TBD

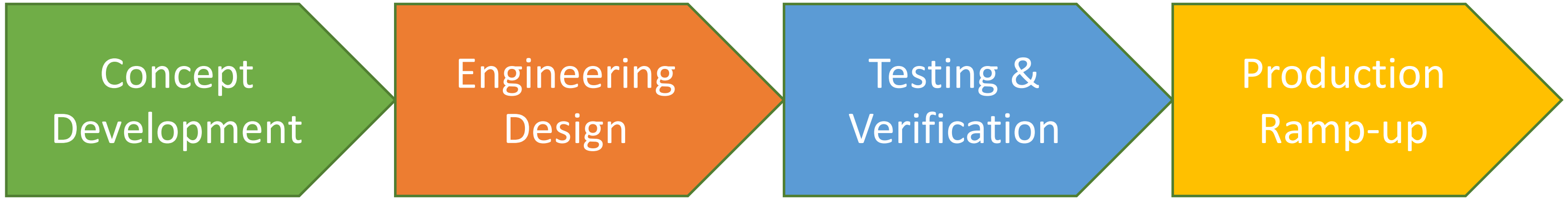


Web wireframe

Here we see that SW requirements often are specified differently [block diagram, wireframe, state machine, text] than HW

Does this cover all the requirements?

Concepts to design



Next, we iterate:

- Market research: what's out there and available, what do our competitors do?
- Draw concepts: form and function
  - This will involve system design and partitioning
- Identify high-risk aspects
- De-risk via:
  - Short-loop prototyping
  - Modeling
  - Research [incl. more market research]
- Update specifications document as needed ← remember this is a *working document*
- Once you have a system design & partition that is suitably stable – go ahead and start detailed design
  - Knowing this may/will iterate back into specs

MILO: market research

- This is an active space
  - For-profit, non-profit, DIY

AirVisual Sensors

AirVisual Series

Everything you need to monitor the air quality inside and outside your home or place of business. The indoor air monitor measures indoor air quality and displays outdoor air quality from the paired outdoor monitor.

Replacement Sensors

AirVisual Pro	$289.00
AirVisual Outdoor	$289.00
AirVisual Bundle	$549.00

	AirVisual Pro	AirVisual Outdoor – 2-PM
		
Sensor Specifications		
PM (Particulate Matter)	0.3 - 2.5 µm	PM2.5: 0.3 – 2.5 µm PM10: 0.3 – 10.0 µm PM1: 0.3 – 1 µm
CO_2 (Carbon Dioxide)	400 - 10,000 ppm (parts per million)	N/A 400 - 10,000 ppm (parts per million)
Temperature	14 to 104 °F (-10 to 40 °C)	-22 to 140°F (-30 to 60°C)
Humidity	0 - 95%	0 - 100% RH, non-condensing

www.iqair.com/us/air-quality-monitors

MILO: market research

NEW: Indoor Air Quality Monitor / PurpleAir PA-I-LED

$209.00

The PurpleAir PA-I-LED air quality monitor's built-in WiFi integration wil you check your air quality through the real-time PurpleAir Map – from anywhere in the world. **Double tap to adjust the brightness** of the hig visible multi-colored LED ring, allowing quick air quality identification fr across the room. Uncluttered and attractive, the PurpleAir indoor monit provides you and your family with industry-leading performance in measuring PM2.5 pollutant levels in your home.

Power Options: No Power Adaptor
USB Color: Black
Quantity: 1

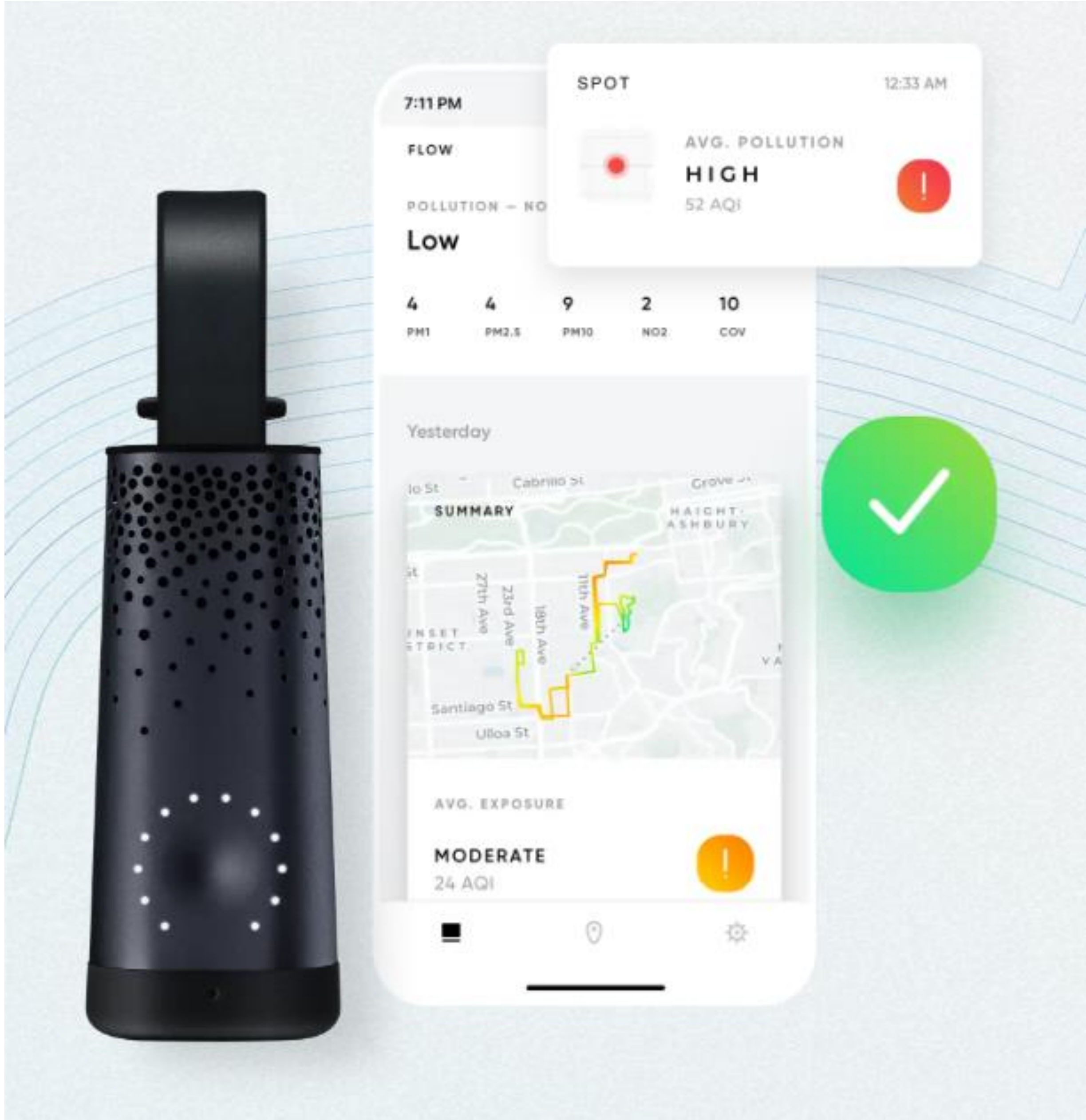
ADD TO CART

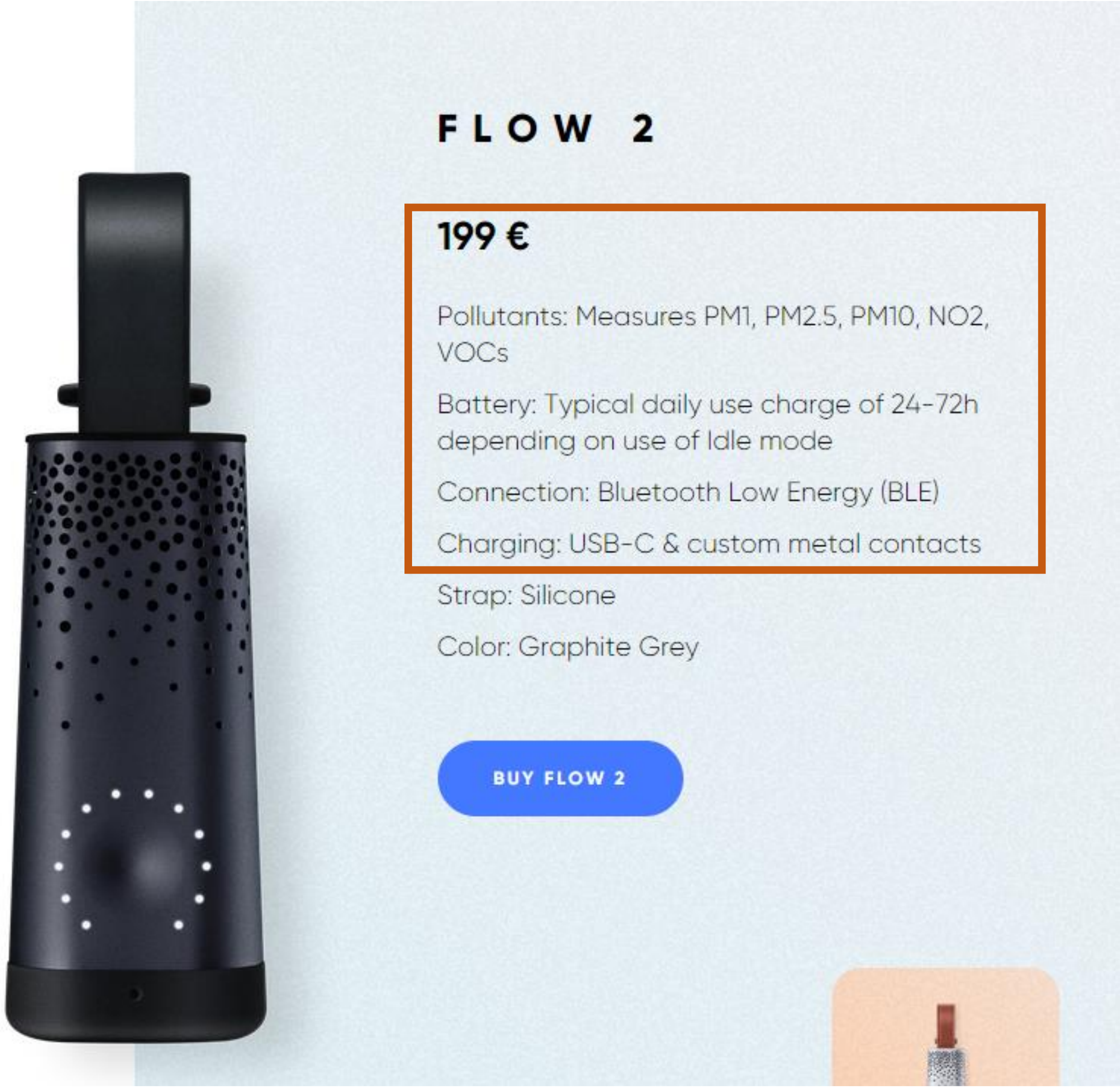
Buy with PayPal

PurpleAir	PA-I-LED	PA-II	PA-II-SD	PA-II-FLEX
Real-Time PurpleAir Map	✓	✓	✓	✓
Pressure, Temperature and Humidity Sensor	✓	✓	✓	✓
WiFi Connectivity with Data Stored in the Cloud	✓	✓	✓	✓
PM1.0, PM2.5 and Particle Counts	✓	✓	✓	✓
Indoor Use	✓	✓	✓	✓
Outdoor Use		✓	✓	✓
Weather Resistant Design		✓	✓	✓
Dual Laser Counters		✓	✓	✓
Built-in SD Card Logging			✓	✓
Full Color Air Quality LED	✓			✓
Single Laser Counter	✓			
Tap Control	✓			
Volatile Organic Compounds	✓			✓
User Replaceable Laser Counters				✓

www2.purpleair.com

MILO: market research





plumelabs.com/en/flow/

MILO: market research

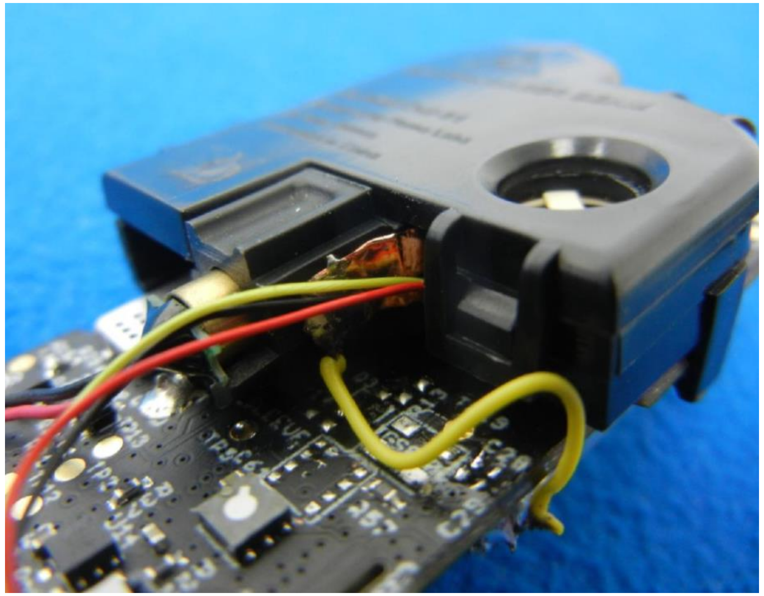
- Many products out there measure PM10, PM2.5, VOC, NOx (and T, RH)
  - But CO2? Pressure?
- AQI: Comprised of **$PM_{2.5}$, PM_{10}, NO_2,** SO_2, CO, O_3 [1h & 8h]

What about these?

Purpleair teardown

drive.google.com/file/d/11Y-x0m3KHEIeb5fRSV8UtnKr9MZzPcdv/view

Flume FCC cert teardown



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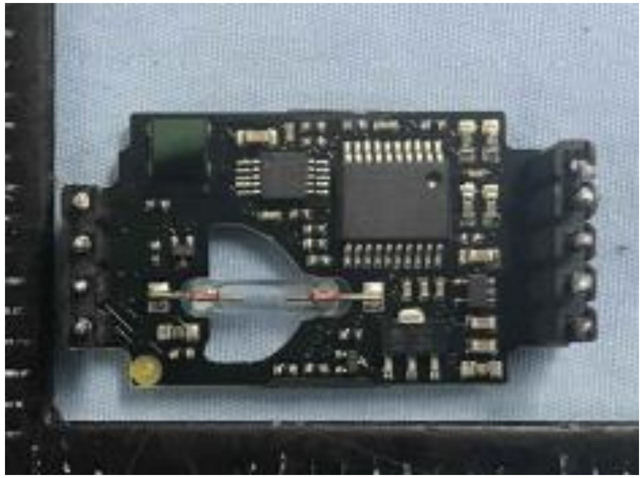
IQAir FCC cert teardown



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MILO: market research

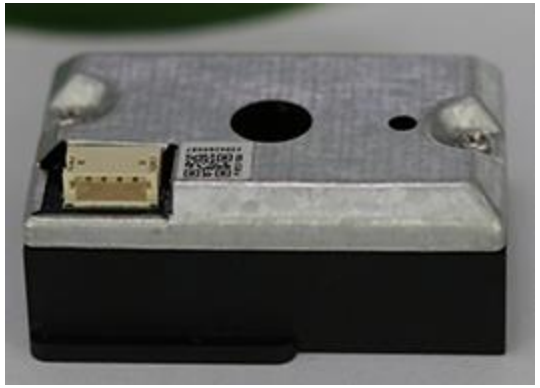
- What sensors are commercially available?
- COTS: commercial off-the-shelf

Particulate: PM2.5, PM10

Plantower PMS series [1003, 3003, etc.]
$10-20/ea

Honeywell HPM series
$70-80/ea

Sensirion SPS30
$30-50/ea



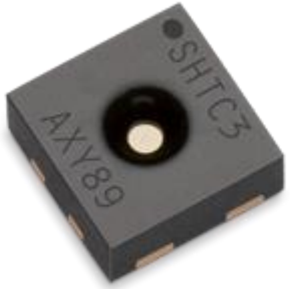
Plantower PIRS10A
Price: ???

MILO: market research

- T/RH are readily available
  - Lots of specs, sizes, costs, etc.
- VOC/NOx also readily available
- Others are less common and/or expensive
  - O_3: $20-50/ea
  - CO: most are $20-50+/ea
  - SO2: $20+/ea

Temperature, humidity
Typically bundled together…why?

TE connectivity TSYS02S
$3-4/ea @10
~7 parts in their product line



Sensirion SHTC3
$2-3/ea @ 10
~25 parts in their product line

Formaldehyde/VOC/NOx

Plantower DS-HCHO-20
~$25/ea

Sensirion SGP41
$5-8/ea @ 10

Bosch BME680
~$10/ea @10

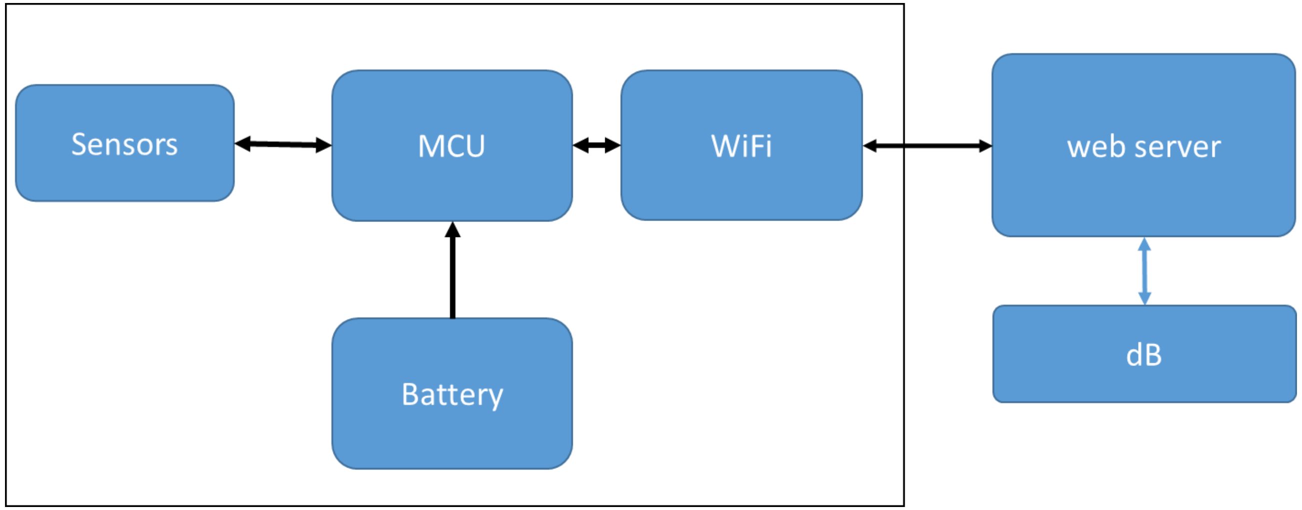
MILO: concepts & systems

- Next, let’s sketch some concepts & systems
- We need to consider
  - Industrial design: what it “looks-like”
  - Engineering: how it functions
- We can “sketch”
  - On paper with pen or pencil
  - On computer in ppt, solidworks, fusion360, etc.

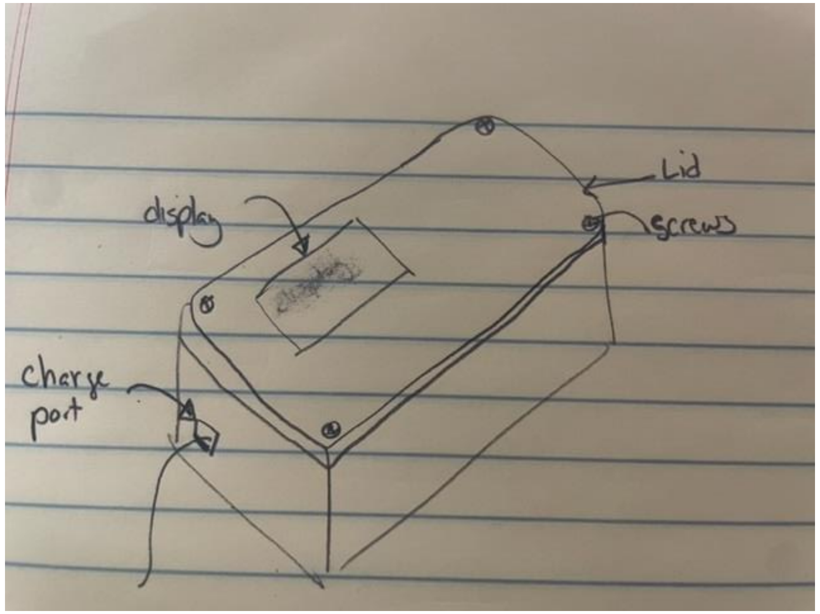
MILO: concepts & systems

- A first system sketch
- We've already decided to forgo O_3, SO_2
  - Too costly
  - Extra complexity not worth the pedagogical value or "time-to-market"
  - Not included in most consumer products

we're missing display!



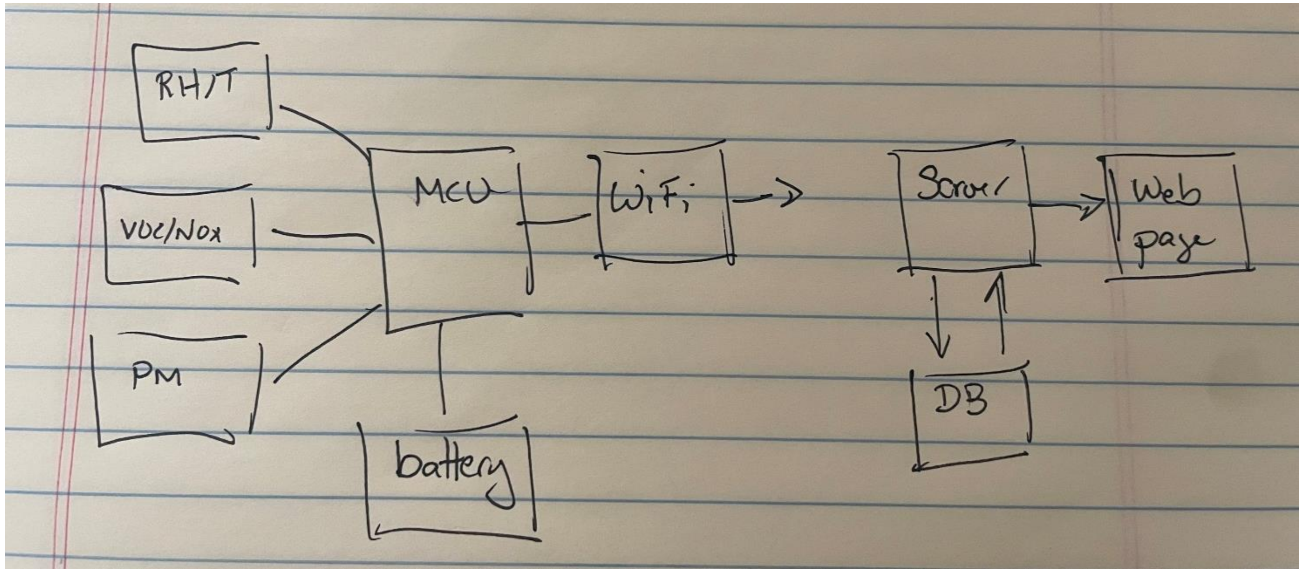
System diagram



Looks-like

MILO: system design & partitioning

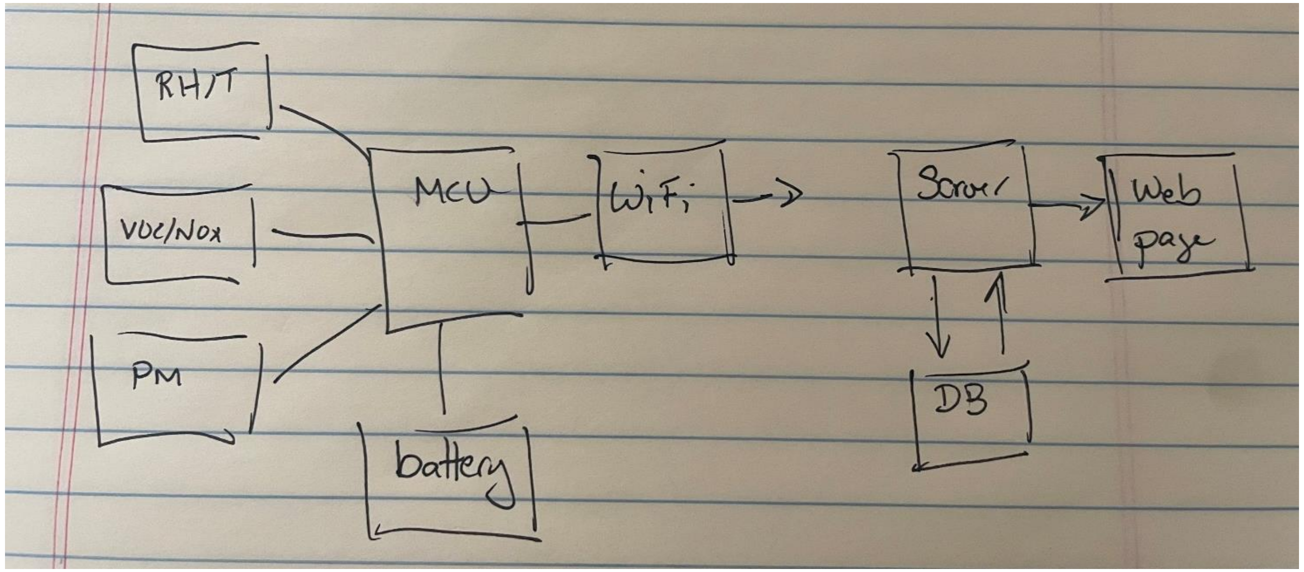
- Our system block diagram starts to imply a system partition
  - Functional partitioning: allocating functions to different parts of the system
  - Physical partitioning: What parts go where, how do they physically connect to each other
- Partitioning can be applied recursively
  - Big blocks into smaller subblocks
- How far to go?
  - As far as needed to make it clear what to design, and so a person/team can start to design
- We partition to manage complexity
  - Subsystems can be designed independently as long as interface is well-defined
  - Allows abstracting away details of other subsystems



Functional

MILO: system design & partitioning

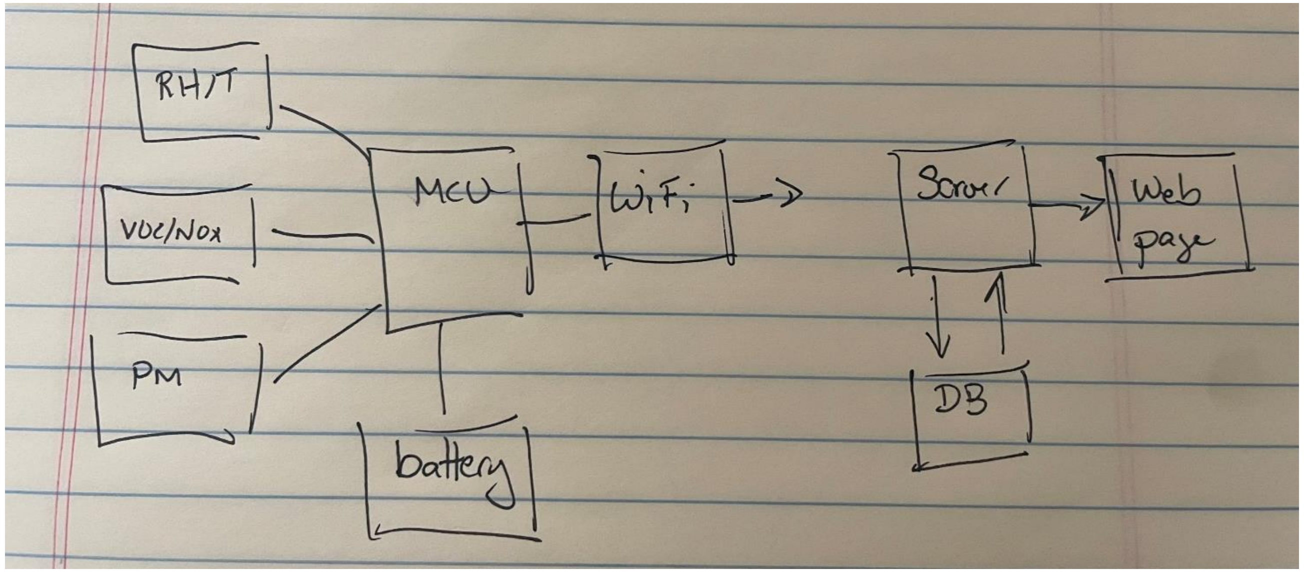
- A good partitioning will have *parts* that
  - Make internal sense –are coherent in terms of the functionality
    - WiFi + RH/T sensor? Probably not
    - RH + T? Maybe
  - Minimize coupling between parts
    - Minimize interfaces
    - Interfaces often translate to connectors, wires, cables, tubes, APIs, function calls, methods, etc.
    - Strong coupling can suggest that parts belong together rather than separate
  - In a company, partitions may be organized by team for each subsystem
    - Sensors/electronics, power, firmware, mechanical, industrial, SWE, backend, frontend, etc.
- There is no optimal partition…



Functional

MILO: system partitioning & tradeoffs

- How do we evaluate/compare designs?
- Trade-off analysis
  - Translate a design back into specs: Performance, cost, size, power, etc.
  - Tradeoff implies that there is no single optimum – it's up to you as the designer to choose!
- Identify
  - High-risk and addressable unknowns
- De-risk
  - Research
  - Model
  - Prototype
- Once your system diagram is stable…move onto detailed design



Functional

MILO specifications [1/2]

Ver. 2

- Financial
  - BOM <= $100 for electronics components, PCB
  - BOM: TBD for enclosure , mechanical parts
  - Time to market: ~8 weeks
- Regulatory
  - FCC certification for WiFi radio module
- Industrial design
  - Weight: < 300 g [~2 iphones]
  - Size: <10 x 10 x 10 cm [kinda small]
  - Survive 12” drop onto table
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- Environmental
  - Operating temperature: 0 to 70°C [commercial temp range]
  - Humidity: 10 to 95% RH
- Engineering
  - Sensors
    - Air quality: NOx/VOC, PM
      - Accuracy: ???
    - T: 0 to 70 °C
      - Accuracy: ???
    - RH: 10 to 95% RH
      - Accuracy: ???
    - Measurement interval: <=10 min
  - Compute
    - MCU: TBD
    - Firmware in C/C++
  - Comms
    - At least WiFi 802.11a/b/g 2.4 GHz
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    - WPA2-Enterprise w/ PEAP (MSCHAPv2) authentication and TLS encryption [this is what MIT Secure wants]
  - Energy management
    - LiPo battery
    - Lifetime between charging: >12 h
  - Server
    - Machine TBD, one for each student
    - SSH access for students, and staff
    - OS: Linux
    - Web server: NGINX
    - HTTPS GET/POST connections
    - DB: SQLite

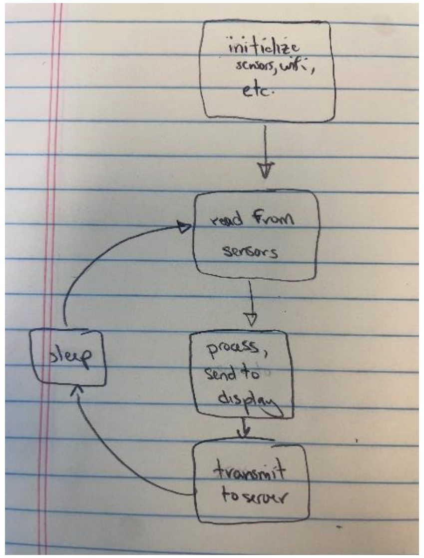
Updates to spec

Things to worry about

MILO specifications [2/2]

Ver. 2

- **Firmware**



- **Still to specify**
  - How to reset?
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- **Software [on server]**
  - Store data perpetually in SQLite table
    - Fields: Index number, Timestamp, RH, T, AQ measurements
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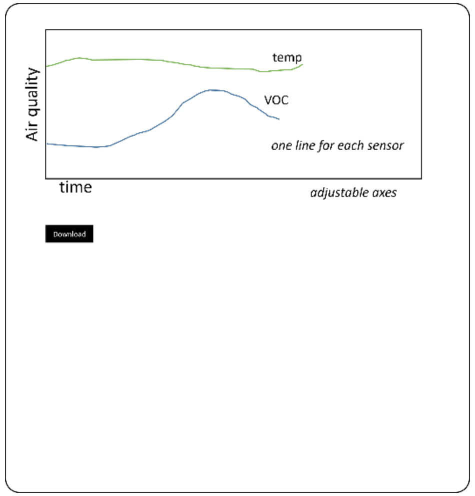
  - Web front-end
    - Framework: TBD



Web wireframe

MILO: de-risking

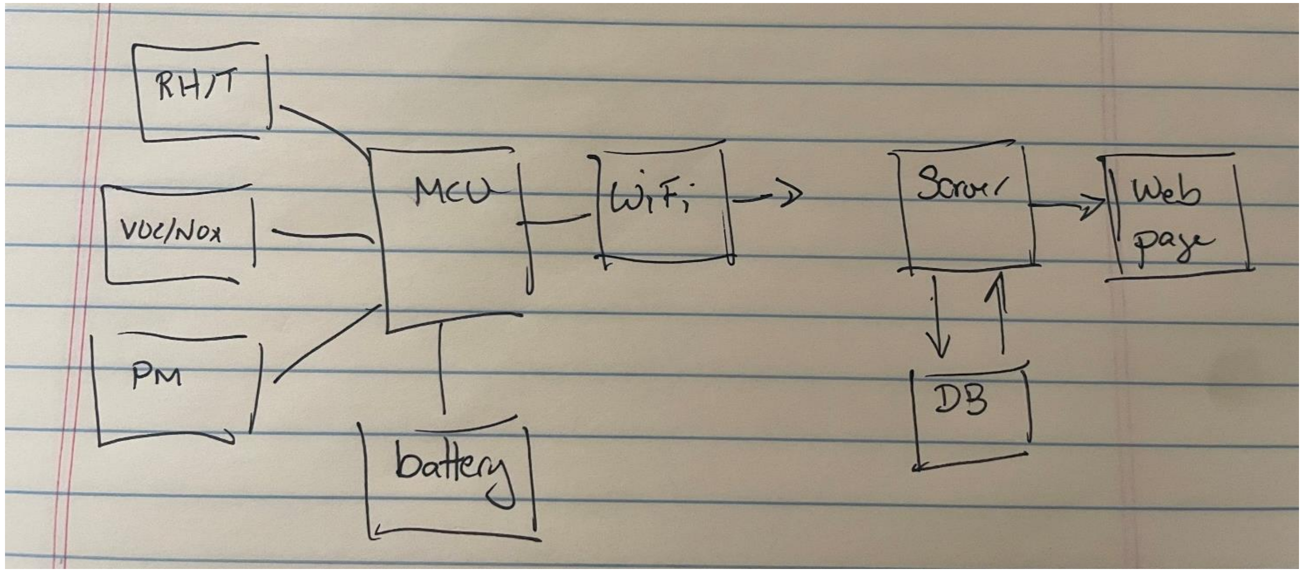
- Some high-risk questions
  - Can we implement in ~8 weeks?
    - Other instructors say PCB design can't work in class setting…
    - So we tested this out a bit over Fall and IAP, and are testing with you!
  - How hard will it be to make these AQ measurements?
- Medium-risk
  - Can we achieve 12 h lifetime?
    - Let's model
    - Rest of electronics are small and light, so plenty of room for beefy battery if needed

What now?

- Research & discuss with team
  - Sensor parts & specs
  - MCU & WiFi choices
  - PCB fab houses
- And iterate! Update system design, specs, concepts

MILO: from specifications to design

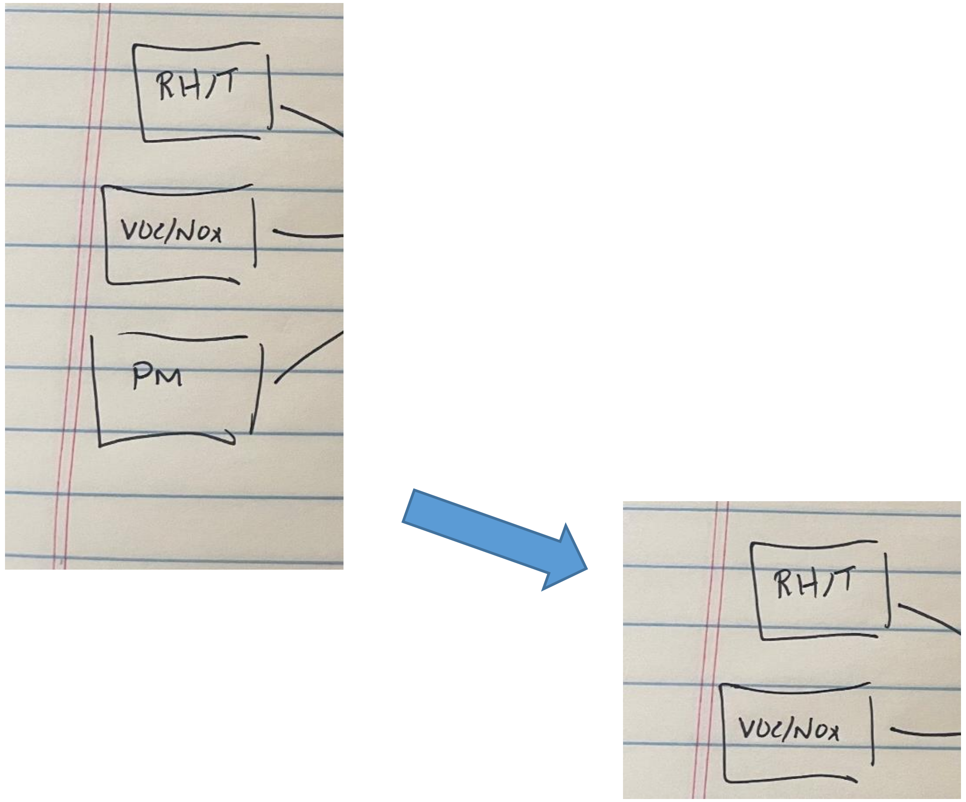
- Much of the content over the next few weeks is intended to help you design systems
  - Labs, psets, and lectures
  - Sensors, compute, comms, etc.
- Let’s look at a few parts in detail



System diagram

MILO: sensors design

- Sensors
  - Connect to MCU, but partitioned separately
  - Because ~0 MCUs have integrated sensors
    - T is exception…more in a few weeks
  - Some sensors do have integrated MCUs
    - Such as for incorporating processing, AI, etc.
    - Reduce part count on board
    - But typically constrained functionality
- RH/T
  - Together, or partition?
  - Almost all RH sensors also include T, so no benefit to separate T
  - ~all RH/T sensors have digital outputs
- VOC/NOx
  - Typically all-in-one part
- PM
  - Decide to remove b/c of:
    - Cost
    - Reasonable tradeoff of pedagogy vs. utility



MILO: sensors design

- What is the interface between sensors and MCU?
- Physical interface
  - Chip-level comms is often via I2C, SPI (sometimes UART)
  - 2+ traces on PCB, 2+ pins on MCU
    - More MCU pins ➔ bigger MCU (sometimes), more expensive
- Functional interface
  - A digital communications protocol: I2C, SPI most common
  - An API/library
    - MCU should have the needed communications peripheral (else you have to bit-bang your own)
    - A set of commands from sensor manufacturer OR a library that encapsulates those commands

4.7 I²C Commands

The available measurement commands of the SGP41 are listed in **Table 8**.

Command	Command hex. code	Parameter length including CRC [bytes]	Response length including CRC [bytes]	Measurement duration [ms]	
				Typ.	Max.
sgp41_execute_conditioning	0x26 0x12	6	3	45	50
sgp41_measure_raw_signals	0x26 0x19	6	6	45	50
sgp41_execute_self_test	0x28 0x0E	–	3	300	320
sgp4x_turn_heater_off	0x36 0x15	–	–	0.1	1
sgp4x_get_serial_number	0x36 0x82	–	9	0.1	1

Table 8 I²C commands available for SGP41.

The datasheet is your friend

Sensirion I2C SGP41 Arduino Library

Sensirion Embedded I2C SGP41 Driver

This is a generic embedded driver for the Sensirion SGP41 sensor. It enables developers to communicate with the SGP41 sensor on different hardware platforms by only adapting the I2C communication related source files.

Sparkfun

- SGP30 Arduino Library: https://github.com/sparkfun/SparkFun_SGP30_Arduino_Library
- SHTC3 Arduino Library: https://github.com/sparkfun/SparkFun_SHTC3_Arduino_Library
- SCD30 Arduino Library: https://github.com/sparkfun/SparkFun_SCD30_Arduino_Library

Adafruit

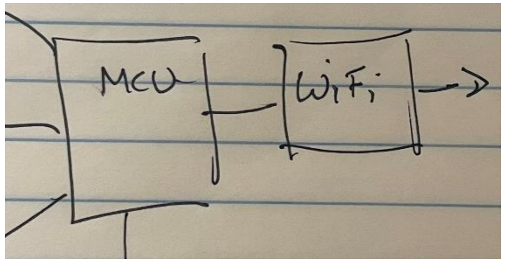
- SHT31 Arduino Library: https://github.com/adafruit/Adafruit_SHT31
- SHT31D CircuitPython Library: https://github.com/adafruit/Adafruit_CircuitPython_SHT31D
- SHTC3 Arduino Library: https://github.com/adafruit/Adafruit_SHTC3
- SHTC3 CircuitPython Library: https://github.com/adafruit/Adafruit_CircuitPython_SHTC3
- SGP30 Arduino Library: https://github.com/adafruit/Adafruit_SGP30
- SGP30 CircuitPython Library: https://github.com/adafruit/Adafruit_CircuitPython_SGP30

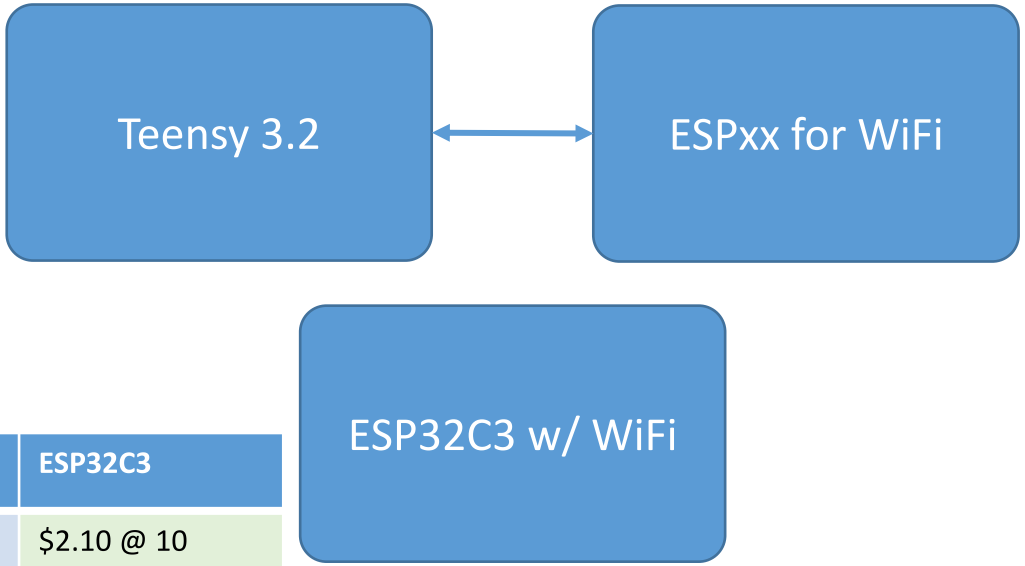
Seeedstudio

- SGP30 Arduino Library: https://github.com/Seeed-Studio/SGP30_Gas_Sensor
- SGP30 Python Driver: https://github.com/Seeed-Studio/Seeed_Python_SGP30
- SHT31 Arduino Library: https://github.com/Seeed-Studio/Grove_SHT31_Temp_Humi_Sensor
- SHT35 Arduino Library: https://github.com/Seeed-Studio/Seeed_SHT35
- SCD30 Arduino Library: https://github.com/Seeed-Studio/Seeed_SCD30

MILO: MCU & comms design

- MCU & comms
  - Details in a few weeks, but…
- Factors influencing choice
  - MCU family
  - MCU w/ or w/o integrated WiFi
  - Peripherals to connect to display, sensors, etc.
  - Price & availability
  - RAM, Flash, etc. ← SW affects HW choice!
  - Use in other classes
  - Etc..
- Examined a few options
  - ATTiny, STM32 family
  - Teensy 4.0 + WiFi module [such as ESPxx]
    - NXP IMXRT1062DVL6 w/ ARM Cortex-M7
  - ESP32C3 [MCU + WiFi]
    - Espressif RISC-V Core





	Teensy4.0 + WiFi	ESP32C3
Cost	$20+ @ 10	$2.10 @ 10
Peripherals [I2C, SPI, ADC, UART, USB]	All that are likely needed	Same
Avail	yes	yes
Used in other classes?	6.200, 6.310	6.190
Number of parts	2 [+passives]	1 [+passives]

Partial list of considerations

MILO: MCU & comms design

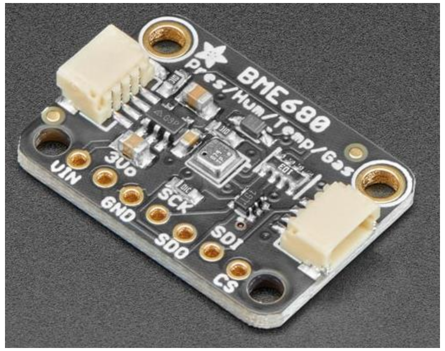
- MCU & comms programming
  - Originally wanted plain C/C++
- Question: how hard to get WiFi stack up-and-running on bare ESP32C3?
- Short-loop prototyping
  - Get ESP32 dev board
  - Try it out!
- Answer: pretty hard

  ➔ Incompatible with time-to-market
- Use Arduino libraries as needed [but no Arduino IDE!]

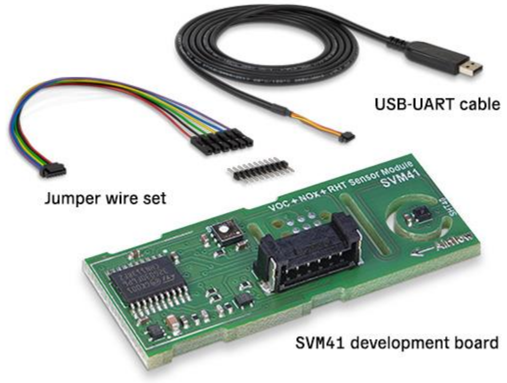
Prototyping for de-risking

We have parts available, or can order for your team!

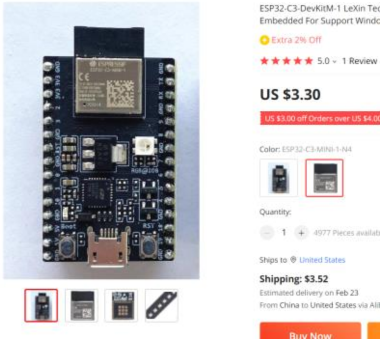
- Some HW aspects we can design and de-risk by research and modeling
- Others require prototyping
- Breakouts are fast/easy way to get started
    - With hardware design, firmware design
    - Breakouts are also useful inspiration when it is time to design your own board
- Many/most of these are available substantially cheaper from China
    - Though may take longer to arrive, may be *sketchy*
- There are also evaluation kits
- For other parts (such as SMT ICs), you can get adapter boards



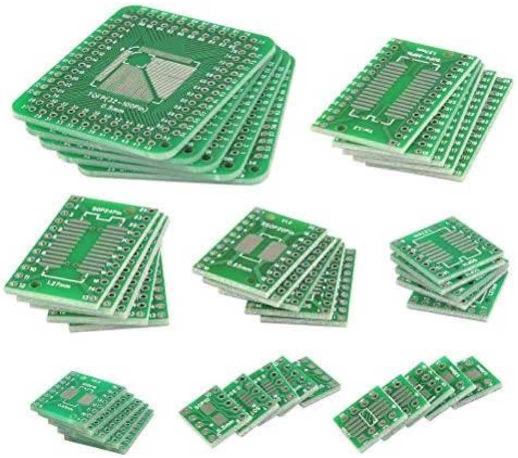
Adafruit Bosch BME680 breakout
$19 @ 1



Adafruit Sensirion SGP40 breakout
$15 @ 1



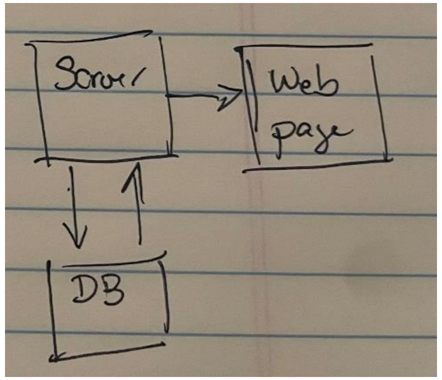
ESP32-C3 dev board
$3.30 @ 1

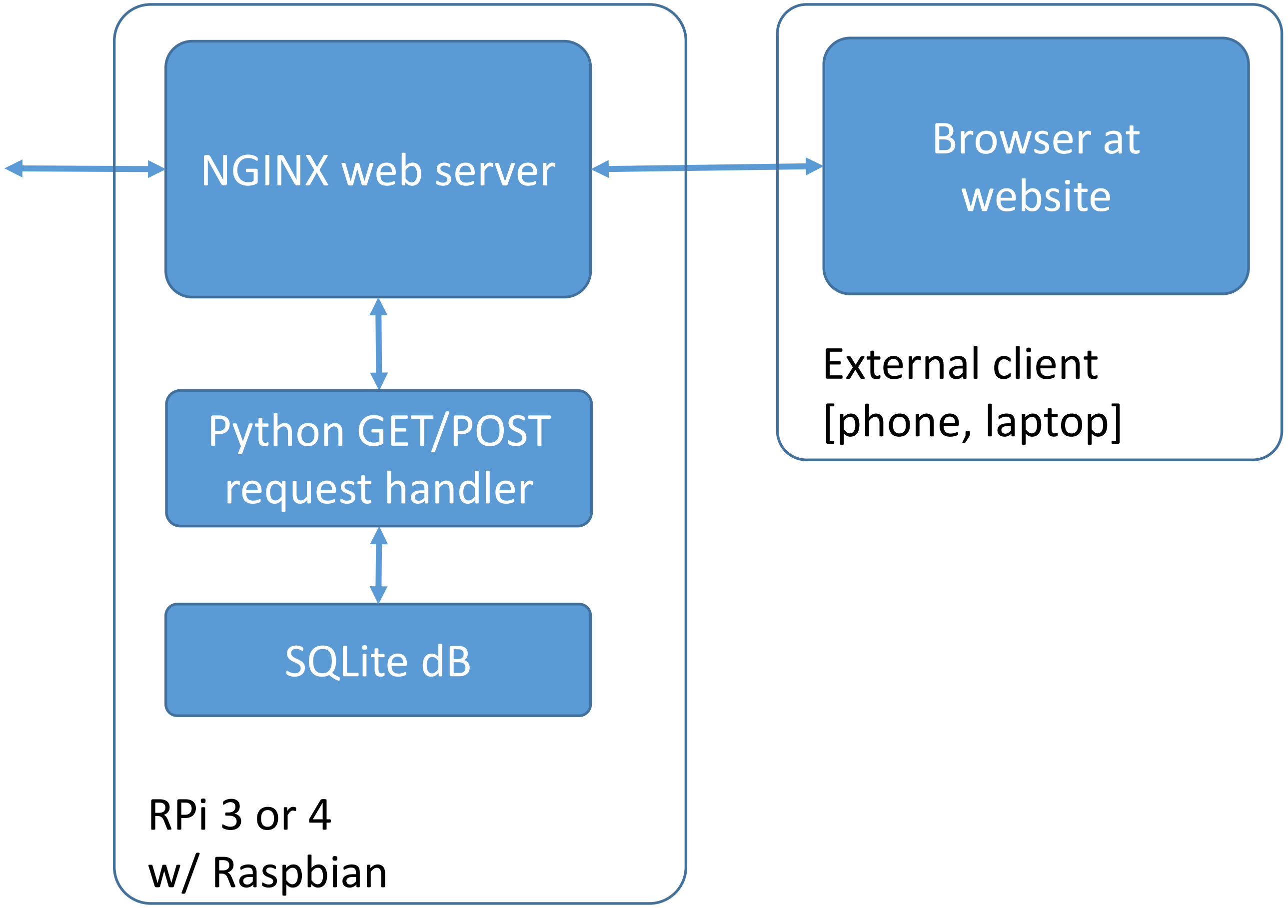


SMD adapter boards

MILO: server design

- Server-side architecture
- Server
  - Cloud provider, like AWS, GCP, etc.?
  - Virtual machines at MIT?
  - Physical machines at MIT?
- Database
  - SQLite, MySQL, etc.
- Web framework
  - Django, Flask, Plot.ly, etc.
- For all these components, pedagogical utility was the primary consideration
  - Expose students to inner workings, do not “black box” unless absolutely necessary
  - As simple as possible, yet authentic
  - Easy to manage and help debug
  - Potential to scale for future course offerings





MILO specifications [1/2]

Ver. 3

Changes to spec
Things to worry about

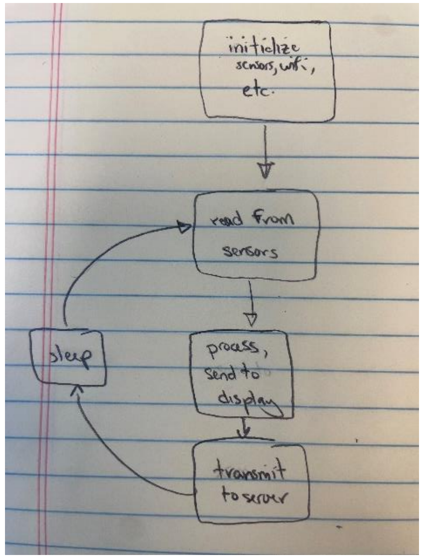
- Financial
  - BOM <= $100 for electronics components, PCB
  - BOM: TBD for enclosure , mechanical parts
  - Time to market: ~8 weeks
- Regulatory
  - FCC certification for WiFi radio module [part of ESP32C3 module]
- Industrial design
  - Weight: < 300 g [~2 iphones]
  - Size: <10 x 10 x 10 cm [kinda small]
  - Survive 12” drop onto table
  - Enclosure materials: 3DP plastics available in EDS, laser-cut plastics available in EDS
- Environmental
  - Operating temperature: 0 to 70°C [commercial temp range]
  - Humidity: 10 to 95% RH

- Engineering
  - Sensors
    - Air quality: NOx/VOC SGP41-D-R4
      - Accuracy is not a provided spec!
    - T: 0 to 70 °C SHTC3-TR-10KS
      - Accuracy: +/- 2% RH
    - RH: 10 to 95% RH SHTC3-TR-10KS
      - Accuracy: +/- 0.2 °C
    - Measurement interval: <=10 min
      - <10 sec response time for SGP41
    - Communications: I2C
  - Compute
    - MCU: ESP32-C3-WROOM-02
    - Firmware in C/C++ w/ Arduino libraries as needed
  - Comms
    - At least WiFi 802.11a/b/g/n 2.4 GHz
    - WPA2-Enterprise w/ PEAP (MSCHAPv2) authentication and TLS encryption [this is what MIT Secure wants]
  - Energy management
    - LiPo battery
    - Lifetime between charging: >12 h
  - Server
    - RPi 3 or 4, one for each student
    - SSH access for students, and staff
    - OS: Raspbian
    - Web server: NGINX
    - HTTPS GET/POST connections
    - DB: SQLite

MILO specifications [2/2]

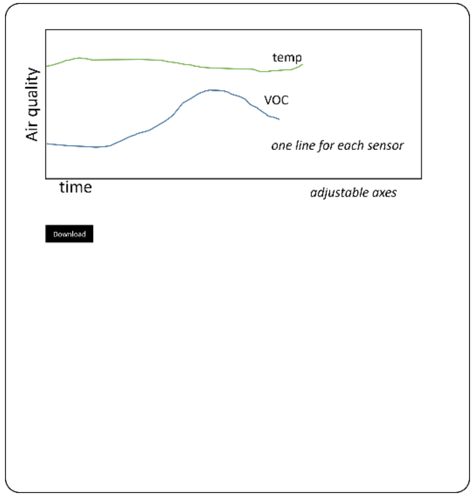
Ver. 3

- **Firmware**



- **Still to specify**
  - How to reset?
  - Functions/APIs for sensor, display, WiFi
  - Data processing and what is transmitted
  - Sleep state, interval

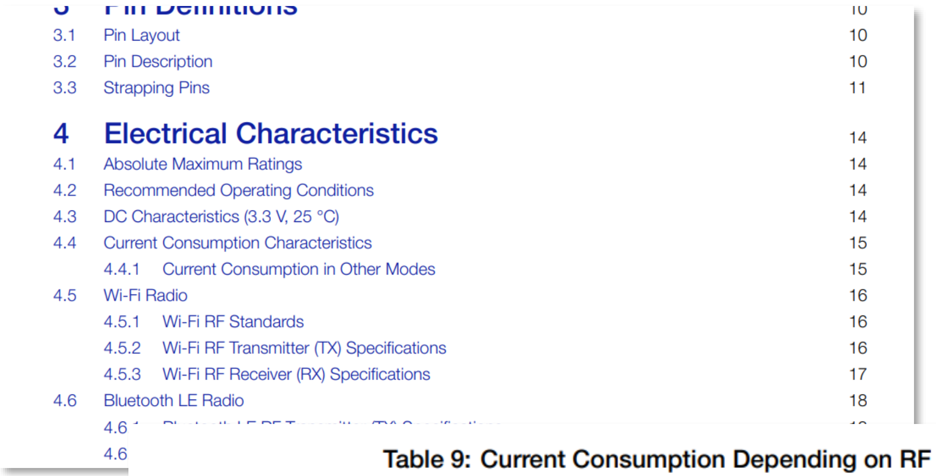
- **Software [on server]**
  - Store data perpetually in SQLite table
    - Fields: Index number, Timestamp, RH, T, AQ measurements
    - No location information transmitted (or stored)
  - Web front-end
    - Framework: TBD



Web wireframe

MILO: Power management – modeling

- Power
  - More in a few weeks…
- Can we estimate the lifetime?
- What's the biggest energy consumer – usually MCU or comms
  - In our case, WiFi
  - Let's check ESP32-C3 datasheet



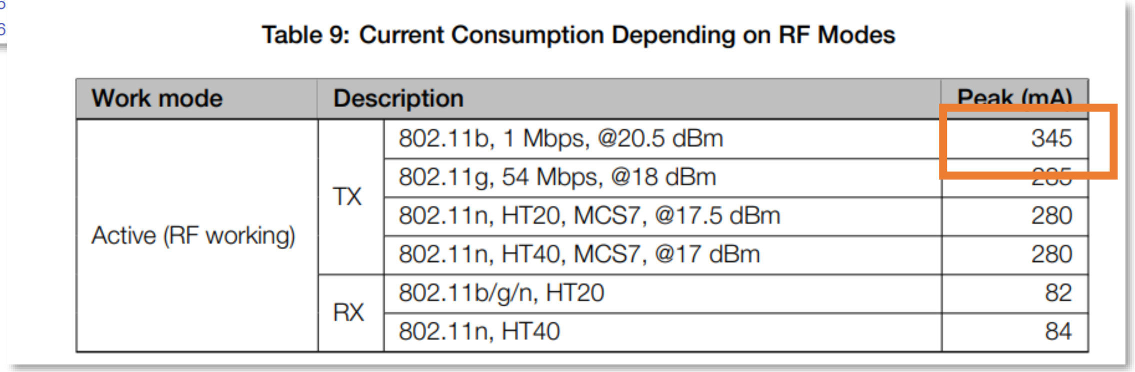


Table 9: Current Consumption Depending on RF Modes

Work mode	Description		Peak (mA)
Active (RF working)	TX	802.11b, 1 Mbps, @20.5 dBm	345
		802.11g, 54 Mbps, @18 dBm	285
		802.11n, HT20, MCS7, @17.5 dBm	280
		802.11n, HT40, MCS7, @17 dBm	280
	RX	802.11b/g/n, HT20	82
		802.11n, HT40	84

- What about battery?
  - ~infinite number of choices
  - Most common rechargeable choice these days is LiPo
  - Let's look at 18650 b/c it is used in 6.08
    - 3.7V nominal for single cell
    - Typical capacities ~2500 – 3600 mAh

Assume 400 mA @ 3.3V consumption
Assume 3600 mAh capacity @ 3.3V [assume no energy savings for 3.7V to 3.3V conversion]

~9h if transmitting WiFi continuously…which we aren't going to be doing ➔ should be ok!

MILO: comms and display

- Many ways to view sensor data
  - Sensor node → on-board display
    - Could remove WiFi/comms entirely in some cases
    - Display adds cost to node
  - Sensor node → Phone→ view on app
    - Directly connect MILO node to phone, such as via Bluetooth
    - Avoid cloud server infrastructure – phone is ubiquitious
  - Sensor node → Phone/gateway → server → view on website
    - Use phone or other device to hand off data from sensor node to internet
    - Allows remote data retrieval, data fusion from multiple nodes/users
    - Need to maintain server, write apps for node, phone, and server
  - Sensor node → server → view on web
    - Not very common (due to power consumption)
    - Avoids need for app on phone, which is why we'll use it!

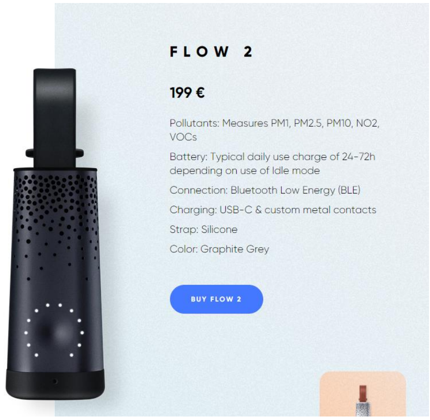
AirKnight 9-in-1 Indoor Air Quality Monitor Indoor Portable CO2 Monitor | VOC Sensor | Formaldehyde Detector AQI PM2.5 + 4 More Home Monitoring | Air Quality Tester - Confined Space Clean Air Monitor

Visit the AirKnight Store

165 ratings | 54 answered questions

-13% $129.99

List Price: $150.00



MILO: specifications

Ver. 4

- Financial
  - BOM <= $100 for electronics components, PCB
  - BOM: TBD for enclosure , mechanical parts
  - Time to market: ~8 weeks
- Regulatory
  - FCC certification for WiFi radio module [part of ESP32C3 module]
- Industrial design
  - Weight: < 300 g [~2 iphones]
  - Size: <10 x 10 x 10 cm [kinda small]
  - Survive 12" drop onto table
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- Environmental
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      - Accuracy: +/- 0.2 °C
    - Measurement interval: <=10 min
      - <10 sec response time for SGP41
    - Communications: I2C
  - Compute
    - MCU: ESP32-C3-WROOM-02
    - Firmware in C/C++ w/ Arduino libraries as needed
    - How to program?
  - Comms
    - At least WiFi 802.11a/b/g/n 2.4 GHz
    - Hardcoded connection to EECS_Labs [open network]
  - Energy management
    - LiPo battery – 18650 w/ JST-PH2 2-pin connectors
    - Lifetime between charging: >12 h
    - System voltage: 3.3 V
    - Charge from USB-micro or USB-C connection
  - Server
    - RPi 3 or 4, one for each student
    - SSH access for students, and staff
    - OS: Ubuntu, any recent LTS
    - Web server: NGINX
    - HTTPS GET/POST connections
    - DB: SQLite

Changes to spec

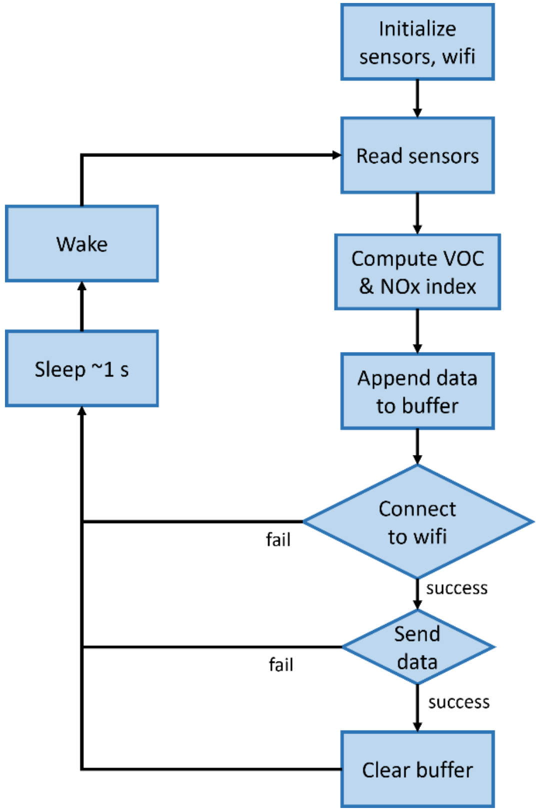
Things to worry about

MILO: specifications

Ver. 4

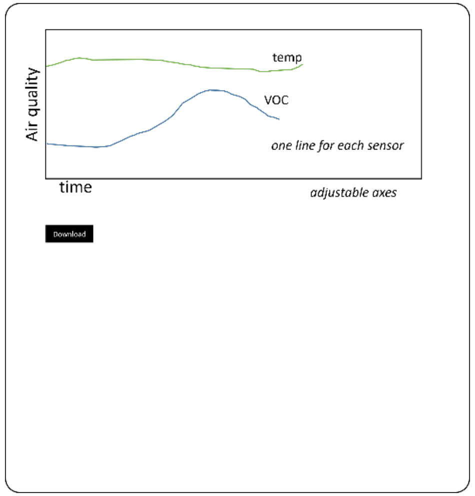
- Firmware

No more display!



- Still to specify
  - How to reset?
  - Functions/APIs for sensor, display, WiFi
  - Data processing and what is transmitted
  - Sleep state, interval

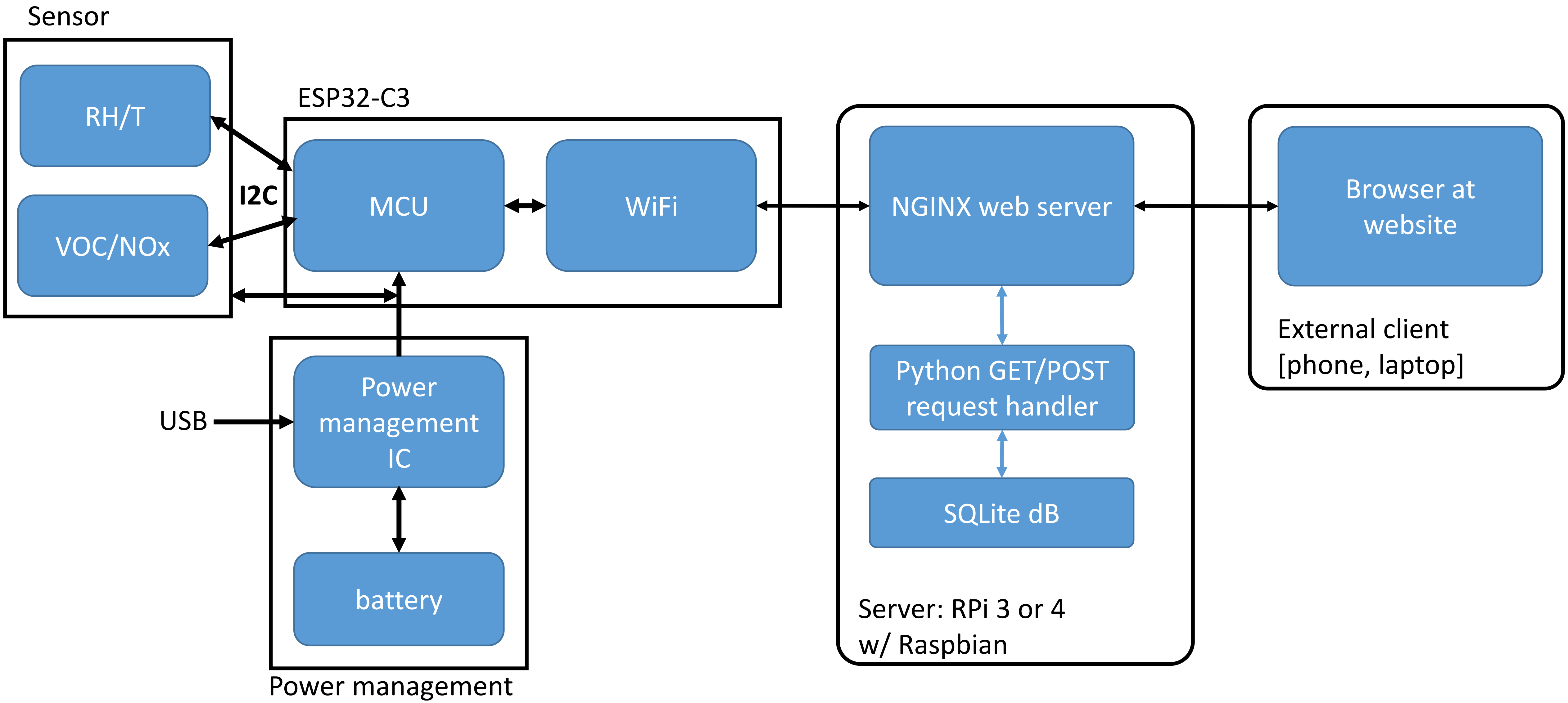
- Software [on server]
  - Store data perpetually in SQLite table
    - Fields: Index number, Timestamp, RH, T, AQ measurements
    - No location information transmitted (or stored)
  - Web front-end
    - Framework: Plot.ly



Web wireframe

MILO: updated system diagram

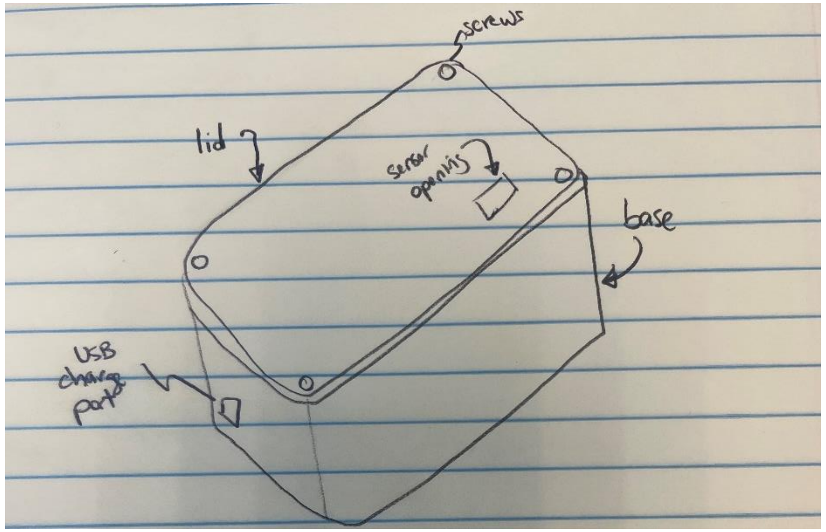
Ver. 4



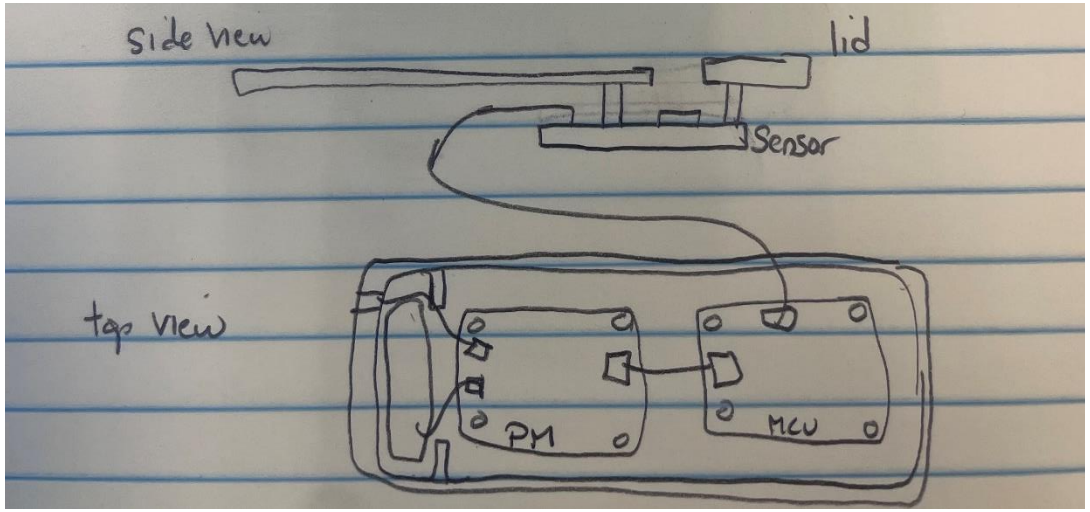
MILO: from requirements to specifications

Ver. 4

- Industrial design



External view



Internal view

3 subsystems ➔3 PCBs

- Still to specify
  - Status LEDs?
  - External buttons?
  - How to program?
  - What do connectors and cables look like, where are they situated?
  - How exactly to expose sensor to world

Test and verification

- Once you make it, does it work? **Does it meet spec?**
  - How will you debug if/when it doesn't work?
- Better yet, can you anticipate testing during design?
  - This is so-called design for test
  - Electronics
    - Make sure all signals are easy to probe: test points!!
    - Status LEDs to quickly see what's going on
    - Jumpers or 0–ohm resistors to connect/disconnect subcircuits
    - Ideally, every pin on a device should be accessible
      - Sometimes you can solve a HW problem with code, scalpel, and a jumper wire
  - Design reviews! Electronics, FW, SW, etc.
    - Find problems early ➔ save $$ and time
  - Test fixtures
    - Example: System with radio comms – how do you do environmental test in a metal chamber?

Test and verification

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  - BOM: TBD for enclosure , mechanical parts
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  - Operating temperature: 0 to 70°C [commercial temp range]
  - Humidity: 10 to 95% RH

And so on…

Testing

- Financial
  - Look at BOM
- Regulatory
  - Done via use of certified module
- Industrial design
  - Weigh it!
  - Measure it!
  - Drop it!
  - Easy to verify
- Environmental
  - This requires an environmental chamber, or contracting with a company. We won’t do this

Test and verification

- FW & SW
  - Tests of each function (unit tests) and overall FW
  - Ideally, not just when everything works, but consider common failures
    - WiFi down…
    - Reset
    - Sensor board disconnected
    - And so on…